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Intended for: 21st APS Shock Compression of Condensed Matter, 2019-06-16 (Portland, Oregon, United States)

Issued: 2019-07-18

The Velocity of Detonation and Reaction Zone Profile in PBX 9502 as a Function of Initial Density

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Abstract. It is known that PBX 9502 changes sensitivity and performance as a function of temperature, presumably due to changes in void morphology and density. These experiments have examined both the velocity of detonation (VOD) and reaction zone profile (particle velocity vs. time) as a function of pressed density. The rate sticks are 2 inches in diameter with an aspect ratio of 1:8. The reaction zone profile was characterized by photonic Doppler velocimetry (PDV) at an aluminized lithium fluoride window and VOD was measured by both piezoelectric pins and time domain reflectometry (TDR). The density range examined was 1.700 - 1.895 g/cc (1.895 is production density). The results obtained are compared to those of in-situ heated rate stick experiments, and the void structure was characterized by small-angle neutron scattering (SANS) methods in order to quantify changes in morphology.

INTRODUCTION

PBX 9502 is an insensitive high explosive (IHE) compound consisting of 95% by weight the HE TATB and 5% Kel-F 800, a flouro-polymer binder. Being an insensitive explosive, PBX 9502 is used for its unusual insensitivity to shock initiation and inability to undergo DDT at any reasonable charge size. Despite its insensitive behavior at ambient conditions, PBX 9502 exhibits an increase in shock sensitivity when heated, although it still is less sensitive than most conventional high explosives even when heated up to 260 °C [1]. Presumably, this steady increase in sensitivity observed with heating [1–5] is due to the change in density as opposed to thermally induced chemical changes. This change in density is due to crystal expansion and reorientation in PBX 9502 [6, 7] and is also the same function that drives ratchet growth, or the permanent volume and density change of PBX 9502 due to thermal cycling [8]. Changes in crystal structure yield a change in void structure, both overall void volume fraction and number of voids [9, 10]. According to the hot-spot theory of detonation initiation [11], this increase in the amount of voids of a critical size present in a bulk charge increases the sensitivity to shock insult. In addition to shock sensitivity, performance characteristics of PBX 9502 also exhibit changes when heated [5, 12–14] including detonation velocity, curvature, and failure diameter. Each of these characteristics is affected by the void structure at the reaction front. The purpose of the research presented here is to be an extension of a previous study [5], examining and quantifying the effects of thermally induced density changes on performance characteristics of PBX 9502. We used specimens pressed to low-density relevant to densities expected at high-temperature in order to remove any thermally induced reaction rate effects.

EXPERIMENTAL SET UP

Experimental Configuration

The experimental configuration used was a rate stick similar to that of previous experiments [5] without the added complexities associated with high temperature. The major differences were the increased diameter of the rate stick along with the addition of the high-resolution time domain reflectometry (HR-TDR) which will be discussed later. Figure 1(a) shows the output face of the experiment with the diagnostics. The LiF window used for PDV is shown in the center. Additionally there were 3 aluminum rods equally spaced 120° around the experiment. The top rod (pictured in the section view) was used to mount the piezoelectric pins to the experiment. The other two rods were used to hold

the HR-TDR cable in contact with the PBX 9502. Figure 1(b) shows a section view of the experimental set-up. As shown, the experiment was initiated by an RP-1 detonator at the apex of a 2 in plane wave lens (PWL). This PWL initiateed a 2 in PBX 9501 booster that is 1/2 in thick, which provided a slight overdriven condition in the PBX 9502. The PBX 9502 section was 2 in in diameter and was 16 in long made up of right circular cylinders 2 in tall. The first 8 in of the PBX 9502 section was undiagnosed as it was expected that this run distance of 4 charge diameters is needed to reach a steady state detonation. The second 8 in section of PBX 9502 is diagnosed for both VOD and reaction zone profile since it was assumed that steady state detonation is achieved in this section.
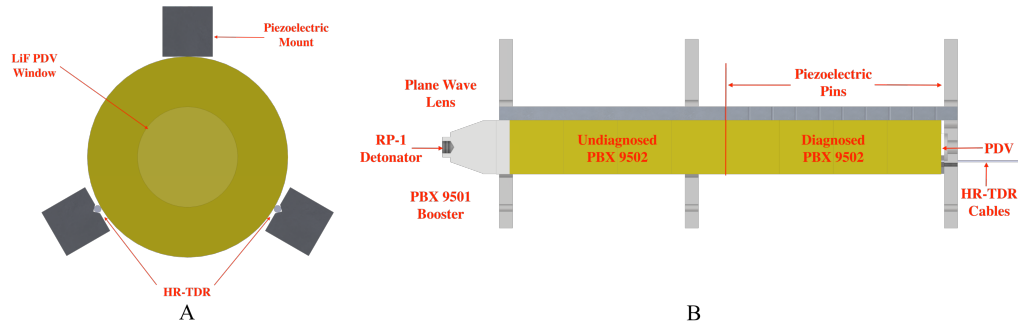

FIGURE 1. Section view of the experimental set up.

Sample Preperation

The specimens used in this experiment were PBX 9502 cylinders pressed to 2.5 in tall x 2.0 in diameter and then machined down to a 2 in length. Pressing to a larger dimension and machining to finish removed a known density and morphology gradient that exists at the pressing ends of a cylinder [15] that would perturb the experimental results. The density range covered in this experiment ranged from a nominal manufacturing density (1895 kg/m^3) down to a density of 1700 kg/m^3.

Diagnostics

Three diagnostics were used in this experiment. The first two diagnostics were piezoelectric pins and HR-TDR. These were used to measure the VOD. The piezoelectric pins used were Dynasen CA-1136 pins and were equally spaced 22 mm apart over the length of the second half of the experimental section. The HR-TDR diagnostic is a relatively new method of measuring VOD [16]. It works by using small diameter coaxial cable, 1.8mm diameter RG-178 in this case, and sending a pulse down the cable and measuring its transit time back. A traveling short is caused by the detonation pressure at the detonation front. This detonation front moves towards the input end of the coaxial cable changing the location of the short and subsequently the time to transmit the signal down the cable and back. This rate of change is equal to the VOD in the explosive. The final diagnostic was PDV used to measure the particle velocity of the breakout surface of the PBX 9502. The PDV system used in this experiment was a heterodyne 1 GHz upshifted system and the probe used was made by AC Photonics. A lithium fluoride (LiF) window with a 1 μm aluminum coating was used at the output face of the PBX 9502. All velocities presented were corrected for the presence of a LiF window [17]. The measurement of this particle velocity of detonation breakout allowed for the characterization of the reaction zone and the inference of detonation pressure.

RESULTS

The VOD results as a function of density are shown in Figure 2 and are seen to decrease linearly with density. The data also show that there is good agreement between the HR-TDR and piezoelectric pin data. The maximum deviation

of velocity gradient between each of the data sets is approximately 7.6%. The data represented by the green markers is the temperature-based data from Rae, Armstrong, & Haroz [5]. Clearly, the same linear relationship between density and VOD exists independent of the method used to achieve low-density.
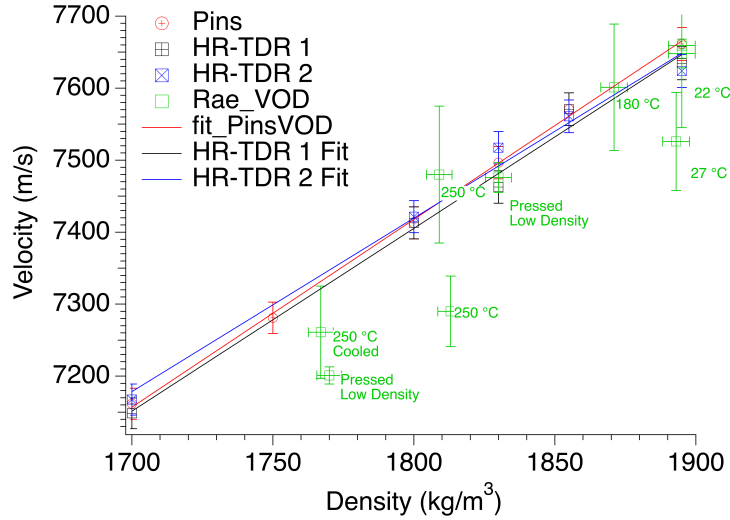

FIGURE 2. Velocity of detonation comparison.

TABLE 1. VOD values as a function of density.

Density kg/m^3	TDR 1 m/s	TDR 2 m/s	Pins m/s
1700	7178	7197	7162
1750	N/A	N/A	7281
1800	7443	7452	7413
1830	7493	7548	7497
1855	7602	7592	7571
1895	7666	7655	7661

The reaction zone data as a function of density is presented in Figure 3. The particle velocity of the reaction zone near the Von Neumann spike is not monotonic with density; however, the following flow is monotonic with density. Also presented in Figure 3 is relevant data from Rae, Armstrong, & Haroz [5] for comparison. The particle velocity at the Von Neumann spike is similar for the heated series, which is not unexpected. The following flow appears not to be monotonic at the smaller 0.5 in scale. PBX 9502 is a non-ideal explosive composition and so the reaction zone is heavily influenced by confinement effects.

Published small-angle neutron scattering (SANS) data of in-situ high-temperature and low-density PBX 9502 [9] allows for examination of the differences in void morphology between the two different scenarios. Figure 4 shows the total void volume fraction of each specimen characterized. The pressed-to-density specimens exhibit a slightly larger void volume fraction than the in-situ heated specimens. Also, the void volume fraction increases substantially when specimens are cooled and is dependent on the temperature achieved. This increase in void volume fraction correlates with the observed behavior of the heated, and the heated then cooled, specimens with respect to VOD.
The mean void size of each specimen type is also shown in Figure 4. The mean void size is highly dependent on the method by which reduced density is achieved. The mean void size is much larger for specimens heated to low-density
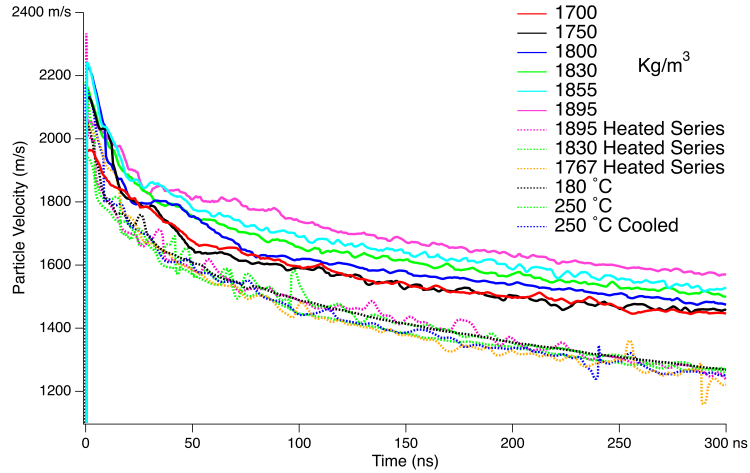
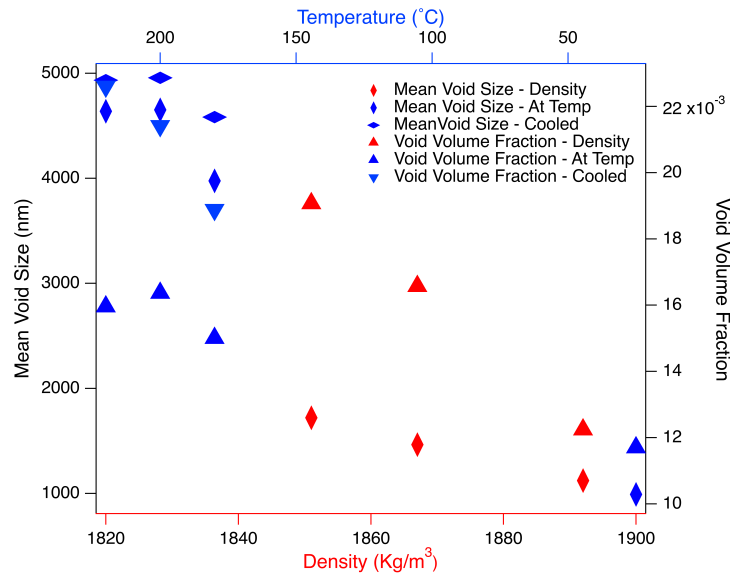**FIGURE 3.** Reaction zone particle velocity profile.

FIGURE 4. Comparison of void volume fraction between heated-to and pressed-to density. Red symbols correspond to the bottom axis (density), and blue to the top (thermal).

than those pressed to low density. Again, as with the void volume fraction the mean void size increases as specimens are cooled after heating.

Discussion and Conclusion

The data presented here only partially address the effects of density and void morphology, both thermally induced and intentionally manufactured, on the VOD and reaction zone profile. The VOD data indicates that as density decreases, VOD decreases linearly. Comparing heated specimens to as-pressed, this trend holds, indicating that the avenue of reduced density is less important than the total void content or density to the VOD of PBX 9502. Further evidence of this is demonstrated with the decreased VOD exhibited by the difference in specimens heated to 250 °C and the specimens heated and cooled. The thermally cycled specimens exhibit a reduced density upon cooling and a subsequently lower VOD. Finally, considering the SANS data, the void volume fraction difference between as-pressed

and heated specimens is small compared to that of the difference in mean void size, indicating that void content is the predominant factor in determining VOD.

The reaction zone particle velocity profile appears to be little affected by density irrespective of how it is obtained. Close to the Von Neumann spike the particle velocity is not monotonic with respect to density, whereas the following flow particle velocity is. Some ambiguity arises when comparing the as-pressed specimens to the heated ones for two reasons. First, the two experiments used different diameter rate sticks. The in-situ heated rate sticks utilized a much smaller diameter of 0.5 in, which is only slightly larger than the unconfined failure diameter of PBX 9502, whereas the as-pressed series utilized a diameter much larger than the failure diameter. Since PBX 9502 is a highly non-ideal explosive it is expected that a sensitivity to charge diameter and confinement would occur. However, the heated series is still above the failure diameter and, considering the differences in void morphology elucidated by the SANS data, there is a substantial difference in the mean void size of PBX 9502 when heated to low-density as opposed to when pressed to low-density. In order to determine whether the difference in reaction zone profile is artificially induced by experimental differences or is a real result indicating a dependency on void morphology, repeating the high-temperature experiments with an equivalent charge diameter to that of the tests in this paper is required.

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